Evaluation of Alternative Landfill Cover Designs
West Lake Landfill Operable Unit-1

Prepared for

The United States Environmental Protection Agency Region VII

Prepared on behalf of

The West Lake Landfill OU-1 Respondents

Prepared by

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January 27, 2015

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11201 Renner Boulevard
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ATTENTION: Mr. Bradley Vann

**SUBJECT: Evaluation of Alternative Landfill Cover Design,
West Lake Landfill Operable Unit 1, Bridgeton, Missouri**

Dear Mr. Vann,

On behalf of Cotter Corporation (N.S.L.), Bridgeton Landfill, LLC., Rock Road Industries, Inc., and the United Sates Department of Energy (the "Respondents"), Engineering Management Support Inc. (EMSI) submits the attached Evaluation of Alternative Landfill Cover Design.

If you have any questions or desire additional information related to this report or any other aspect of the project, please do not hesitate to contact us.

Sincerely,
ENGINEERING MANAGEMENT SUPPORT, Inc.

Paul V. Rosasco, P.E.

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List of Acronyms

ASTM	American Society for Testing and Materials
CCL	Compacted Clay Layer
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
CFR	Code of Federal Regulations
CH	“clay of high plasticity, fat clay” group symbol in the USCS
CL	“clay of low plasticity, lean clay” group symbol in the USCS
CSR	Code of State Regulations
EMSI	Engineering Management Support, Inc.
EPA	U.S. Environmental Protection Agency
FS	Feasibility Study
GCL	Geosynthetic Clay Liner
HDPE	High Density Polyethylene
HELP	Hydrologic Evaluation of Landfill Performance
MDNR	Missouri Department of Natural Resources
MH	”silt of high plasticity, elastic silt” group symbol in the USCS
ML	“silt” group symbol in the USCS
NAS	National Academy of Science
NRC	National Research Council
OSWER	Office of Solid Waste and Emergency Response
OU	Operable Unit
RCRA	Resource Conservation and Recovery Act
RIM	Radiologically-Impacted Material
ROD	Record of Decision
SC	“clayey sand” group symbol in the USCS
SFS	Supplemental Feasibility Study
UMTRCA	Uranium Mill Tailings
USCS	Unified Soil Classification System

1. INTRODUCTION

This report presents an evaluation of an alternative landfill cover technology for the remedial action for Operable Unit-1 (OU-1) of the West Lake Landfill Superfund Site. The evaluations presented in this report were prepared in accordance with the Revised Work Plan – Alternative Landfill Cover Design dated February 21, 2014 (EMSI, 2014) that was approved by the United States Environmental Protection Agency (EPA) on September 19, 2014.

1.1 Background

In an October 12, 2012 letter (EPA, 2012), EPA Region 7 requested that the West Lake Landfill Operable Unit-1 (OU-1) Respondents, among other things, evaluate potential alternative landfill cover designs.[1] The Respondents developed a Revised Work Plan for Alternative Landfill Cover Design (EMSI, 2014) that presented a scope of work for evaluation of the potential application of an alternative cover incorporating a synthetic material layer, specifically a geosynthetic clay liner (GCL), into the design of the landfill cover for OU-1.

1.2 Scope of the Evaluation

This report presents an initial screening and a detailed evaluation of a GCL in the landfill cover design. A GCL is a factory-manufactured hydraulic barrier consisting of a layer of bentonite clay supported by geotextiles and/or geomembranes and held together by needle punching, stitching, or chemical adhesives (Rowe, 2005). The alternative landfill cover evaluation is focused on the possible use of a GCL because of the potential benefits of and suitability for using a GCL in a landfill cover at OU-1.

GCLs have been employed since the mid-1980's and are now routinely used (Bouazza and Bowders, 2010). Use of natural bentonitic materials is preferred due to the overall longevity and durability of natural materials as compared to man-made synthetic materials. Furthermore, as detailed below, GCLs have been shown to be easier to install, can be deployed more quickly and do not require water, require less quality assurance checking during installation, and typically can be installed at a similar cost to a compacted clay layer (CCL) [CETCO, 2000, EPA, 1993a, and Koerner and Daniel, 1993] even when clay is locally available.

The evaluations presented in this report were performed using the procedures for screening remedial technologies and process options for remedial alternatives set forth in EPA's "Guidance for Conducting Remedial Investigations and Feasibility Studies Under CERCLA (EPA, 1988a).

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[1] EPA specifically requested evaluation including, but not limited to, an Evapo-Transpiration (ET) Cover for OU-1. In addition, EPA had previously indicated that the National Remedy Review Board wanted the use of synthetic cover materials evaluated as part of the Supplemental SFS. A Scope of Work and Schedule for the Alternative Landfill Cover Designs was prepared and submitted to EPA on February 3, 2013. Comments were provided by the Missouri Department of Natural Resources (MDNR) in a letter dated May 9, 2013. EPA comments on the scope of work were provided on August 16, 2013. During a September 24, 2013 meeting, EPA indicated that an ET cover was not applicable to OU-1.

These are the same procedures that were used previously to screen and evaluate other remedial technologies and process options in the Feasibility Study ("FS") [EMSI, 2006] and Supplemental Feasibility Study ("SFS") [EMSI, 2011]. Based on the results of the evaluations presented in this report, this report recommends the development and evaluation of a remedial action alternative that incorporates a GCL into a potential landfill cover as part of the Supplemental SFS for OU-1.

Descriptions of the engineered landfill cover included as part of the remedy selected in the EPA's Record of Decision for OU-1 ("ROD") and the alternative landfill cover that includes a GCL are provided in Section 2. Section 3 presents the technical screening of the implementability of using a GCL in the landfill cover design. The evaluation of the effectiveness, implementability and cost of an alternative landfill cover design incorporating a GCL is presented in Section 4. Section 5 presents an overall summary and recommendations. Technical papers and other reference material cited in this report are listed in Section 6.

2. LANDFILL COVER DESIGN

This section describes the general design of the landfill cover included in the ROD-selected remedy and the alternative landfill cover design evaluated in this report.

2.1 Landfill Cover included in the ROD-selected Remedy

The ROD-selected remedy includes an enhanced Resource Conservation and Recovery Act (RCRA) Subtitle D (solid waste) cover system to be installed and maintained over OU-1 Areas 1 and 2 (EPA, 2008). This cover system would at a minimum be designed to meet the requirements for final cover systems at municipal solid waste landfills and the Missouri closure and post-closure requirements for sanitary landfills (10 CSR 80-3.010(17)(C)4.A.), with additional enhancements to meet control standards for uranium mill tailings sites (i.e., armoring layer, protection against gamma radiation, and radon barrier) [40 CFR § 192.02].

Specifically, the design of the landfill cover under the ROD-selected remedy is anticipated to consist of the following layers (from top to bottom):

- A one-foot thick layer of soil capable of sustaining vegetative growth;

- A two-foot thick infiltration (low permeability) layer of compacted USCS CL, CH, ML, MH, or SC soil-type with a coefficient of permeability of 1×10^{-5} cm/sec or less; and

- A two foot thick bio-intrusion/marker layer consisting of well-graded rock or concrete/asphaltic concrete rubble.

Such a cover system includes a low permeability layer, in this case the two-foot thick low permeability layer described above, to minimize the potential for percolation (infiltration) of rainfall or snowmelt to move through the cover and enter the underlying waste materials, thereby potentially resulting in generation of landfill leachate.

2.2 Landfill Cover Incorporating a Geosynthetic Clay Liner Layer

There are several types of geosynthetic products that are often used in landfill containment design that could be considered as an alternative to the soil-only landfill cover prescribed in the ROD-selected remedy. For example, geomembranes or GCLs are often used as low-permeability components, and geonets and geotextiles are often used as drainage layers (EPA, 1993a, Bonaparte et al., 2002, Rowe, 2005, and NAS-NRC, 2007). A GCL was considered as a representative process option for purposes of screening and evaluating technologies for alternative landfill cover designs. A GCL is a factory-manufactured hydraulic or gas barrier consisting of a layer of bentonite or other very low permeability material supported by geotextiles and/or geomembranes, mechanically held together by needling, stitching, or chemical adhesives (Bouazza and Bowders, 2010). Because of the extremely low permeability to liquids and gases of the bentonite clay component, as well as other site-specific advantages, in most applications GCLs have served as replacement materials for, or otherwise used to augment, the more traditional soil-based low permeability infiltration layers since their introduction in the mid-1980's (Bouazza and Bowders, 2010, EPA, 1992, 1993a, 1993b, 2001 and 2004, Koerner, 2005, and MDNR, 1997).

This report evaluates the use of a GCL in place of the low permeability compacted soil layer portion of the landfill cover included in the ROD-selected remedy. Although use of a GCL for all or a portion of the low permeability layer of the landfill cover could be considered an alternative cover design from the perspective of the Missouri solid waste regulations for a landfill cover over an existing sanitary landfill without a composite liner (10 CSR 80-3.010(17)(C)4.A.), based on EPA's general acceptance of the use of a GCL for a landfill cover system (EPA, 2001), use of a GCL is anticipated to be an acceptable method for design and construction of an alternative landfill cover.

3. TECHNICAL IMPLEMENTABILITY SCREENING

The potential implementability of the GCL alternative landfill cover design for OU-1 Areas 1 and 2 was evaluated in the same manner that the potential applicability of other technologies were evaluated in the SFS. Specifically, an initial technical implementability screening evaluation was performed to assess the potential applicability of using a GCL as an alternative process option for all or part of the low permeability layer prescribed in the ROD remedy.

A GCL is a relatively thin layer of processed bentonite either bonded to a geomembrane or fixed between two sheets of geotextile. A geomembrane is a polymeric sheet material such as high-density polyethylene (HDPE) that is essentially impervious to liquid as long as it maintains its integrity. A geotextile is a woven or nonwoven sheet material that provides a filtration, separation, or reinforcement function, rather than the barrier function provided by a geomembrane.

As shown in the cross-sections on Figure 1, bentonite is affixed to synthetic materials in a number of ways to form a GCL. In the non-reinforced configuration using a geomembrane or two geotextile layers, the clay is affixed using an adhesive. In a cover system application, the GCL shown with a geomembrane would be placed with its geomembrane side up. Non-reinforced GCLs are only used on very flat surfaces. Adhesives, stitchbonding, needlepunching, or a combination of the three are used in the reinforced geotextile configurations. Although stitchbonding and needlepunching create small holes in the geotextile, these holes are sealed after installation of the GCL when the clay layer portion of the GCL hydrates and swells. Reinforced GCLs are used on relatively steep slopes (EPA, 2001 and Bouazza and Bowders, 2010).

Each type of GCL also has a number of subvariations. For example, the CETCO Bentomat® CL is a reinforced GCL consisting of two carrier geotextiles encapsulating a layer of VOLCLAY sodium bentonite, with a 5 to 60 mil HDPE flexible membrane laminated to one side used for landfill covers on surfaces with a slope ratio of 3 horizontal to 1 vertical (3H:1V or 3:1) or less (CETCO, 2014). For applications involving steeper slopes, the more robust needlepunched CETCO Bentomat® CLT type GCL consisting of a reinforced GCL with a layer of VOLCLAY sodium bentonite between two geotextiles and laminated to a 20 to 60 mil textured HDPE geomembrane would be used (CETCO, 2014) because the texture and needlepunching provide greater internal and interfacial shear strengths (Thiel, et al., 2002).

GCLs are very thin, typically 7 to 10 mm in thickness when hydrated (Koerner and Daniel, 1993). GCL products are shipped in rolled sheets ranging from 13 to 18 feet wide and from 100 to 200 feet long. During installation, the large sheets are rolled-out onto the site subgrade, which should be smooth, well compacted, relatively dry and absent obvious puncture-related threats, such as sharp protruding objects. During installation, adjoining sheets are overlapped to guard against the potential opening of the barrier system. In areas of steeper slopes, GCLs are rolled-out starting at the top of the slope.

Cover soil needs to be placed over the GCL within a period of approximately 24 hours after sheets of GCL are rolled-out. A minimum of 12 inches of free-draining soil cover ballast is needed to prevent the bentonite within the GCL from migrating and thinning, provide confining stress to the GCL, eliminate the potential for seam separation, prevent damage by equipment, as well as to eliminate bentonite free swelling and maintain the hydraulic performance of bentonite (CETCO, 2010). After the GCL layer is covered with soil, the GCL hydrates by drawing moisture from the subgrade and cover soil. Depending on the end use of the cover service, additional thickness of soil cover may be necessary above the GCL to protect the GCL from physical and environmental conditions that may damage it.

GCL technology can provide barrier systems with low hydraulic conductivity (i.e., low permeability), which is the rate at which a liquid passes through a material. Laboratory tests demonstrate that the hydraulic conductivity of dry, unconfined bentonite is approximately 1×10^{-6} cm/sec. When saturated, however, the hydraulic conductivity of bentonite typically drops to 5×10^{-9} cm/sec or less (EPA, 2001 and CETCO, 2013). The hydraulic conductivity for GCLs employing geomembranes is even less, ranging as low as 1×10^{-12} cm/sec depending on the type and amount of bentonite, the amount of additives, the type and thickness of the geomembrane, the product configuration, and application (i.e., whether the GCL is a component of a landfill liner or cover) [EPA, 2001]. For example, the certified hydraulic conductivity of the CETCO Bentomat® CLT type GCL mentioned earlier is 5×10^{-10} cm/sec. The lower hydraulic conductivity of the GCL composite barriers (that employ both the bentonite layer and a geomembrane) when properly installed is due to the presence of the geomembrane.

With respect to the cover system for Areas 1 and 2 of the West Lake Landfill, a GCL alone could not be directly substituted for the two-foot thick infiltration layer and installed directly on top of the bio-intrusion/marker layer. A foundation layer of 6 inches or greater thickness would need to be constructed on top of the bio-intrusion/marker layer to provide a smooth surface upon which the GCL could be placed to avoid punctures in the GCL. This foundation layer could be comprised of sand or compacted clean soil or clay fill with a smooth surface free of rocks or other obtrusions.

The cover of the ROD-selected remedy would be constructed to achieve a minimum slope of 2%. There are several areas within and along the bermed edges of Areas 1 and 2 where the existing cover approaches or exceeds MDNR's 25% maximum slope requirement for landfill covers. Portions of the landfill berm that contain slopes greater than 25% would be regraded through placement of additional material or cutting and filling of existing material to reduce the slope angles to 25% or less subject to physical constraints associated with the location of the toe of the landfill relative to the property boundary. If a GCL were employed as the low permeability layer for the ROD-selected remedy cover system, a reinforced GCL would be required, at least on the steeper slopes. In addition, a sand/gravel or geocomposite drainage layer would be included between the top of the GCL and the cover soil layer to prevent accumulation of water and resultant buildup of soil pore pressures that could lead to slope stability failures. The varying slope conditions of the landfill cover would dictate the GCL configurations that would be incorporated in the cover design. Slope stability analyses would need to be conducted during cover design.

A cover that would employ the GCL technology as an alternative representative process option to all or part of the infiltration layer prescribed in the ROD remedy is implementable. A smooth-surface foundation layer must be provided below the GCL and if the GCL is installed at the top of the infiltration layer, a drainage layer above the GCL should be included. Since the result of the technical implementability screening is that the GCL technology could be implemented for the OU-1 remedy at the West Lake Landfill, the technology was further evaluated for effectiveness, implementability and cost.

4. POTENTIAL EFFECTIVENESS, IMPLEMENTABILITY AND COST

Since the initial screening indicated that use of a GCL is potentially applicable to OU-1, the GCL technology was then subjected to further evaluation using the criteria of potential effectiveness, implementability and cost. During this phase, the anticipated performance of a cover incorporating a GCL was compared to that of the cover specified in the ROD-selected remedy.

4.1 Effectiveness

In addition to the overall purpose of meeting the relevant and appropriate requirements of the solid waste and the Uranium Mill Tailings Radiation Control Act (UMTRCA) regulations (40 CFR § 192.02), the primary goals of the landfill cover are as follows:

- To isolate the underlying waste materials from possible contact or exposure by humans or potential environmental receptors;
- To provide sufficient shielding against gamma radiation;
- To reduce infiltration of precipitation into the waste materials and resulting potential for leachate generation; and
- To reduce radon migration in order to allow for a sufficient amount of the emanated radon to decay within the landfill mass/cover system before it is exhaled (emitted) at the ground surface.

The first two objectives are achieved by placement of a landfill cover of sufficient thickness that would prevent inadvertent or intentional exposure to the wastes and shield against gamma emissions from the radiologically-impacted material (RIM) in Areas 1 and 2. Inclusion of a GCL component in the design of the landfill cover is not expected to result in a significant change in the overall thickness of the landfill cover and, therefore, the first two objectives listed above should be met by either the landfill cover system included in the ROD-selected remedy or by an alternative landfill cover design that includes a GCL component. The ability of the landfill cover designs to provide sufficient shielding is evaluated as part of the detailed evaluation of remedial alternatives performed as part of the SFS evaluations.

Inclusion of a GCL component as part of an alternative landfill cover design is expected to reduce infiltration to the same or potentially even a greater magnitude than that provided by the CCL included in the ROD-selected remedy landfill cover design (EPA, 1996). Evaluations performed by EPA (EPA, 2001), other researchers (Bouazzza and Bowders, 2010 and Bonaparte et al., 2002), and geosynthetic manufacturers (CETCO, 2014) have concluded that a GCL-based cover system will perform similar to, if not better than, a compacted clay landfill cover as long as the required hydraulic conductivity of the GCL is maintained.

An alternate landfill cover system configuration that included a GCL component was subjected to a preliminary evaluation using EPA's Hydrologic Evaluation of Landfill Performance (HELP) model (Schroeder et al., 1994a and 1994b). The GCL alternative landfill cover design considered includes the following layers (from top to bottom):

- A one-foot thick layer of soil capable of sustaining vegetative growth;

- A one-foot thick free-draining sand cover ballast above a GCL;

- A GCL with a permeability of at least 1 x 10^{-7} cm/sec (Note: the CETCO Bentomat® CLT that would be considered for this alternative has a certified permeability of 5 x 10^{-10} cm/sec);

- A one-foot thick well-compacted smooth foundation layer constructed of suitable fill material; and

- A two foot thick bio-intrusion/marker layer consisting of well-graded rock or concrete/asphaltic concrete rubble.

Results of the preliminary HELP modeling for the cover configuration using a GCL indicated that the predicted annual infiltration rate was an extremely low 0.2 inches per year, which meets the goal of reducing infiltration of precipitation.

The alternative landfill cover design would also need to be of sufficient thickness and design to retard or divert the vertical migration of radon consistent with the UMTRCA standards set forth in 40 CFR 192.02(b). The cover system must provide reasonable assurance that releases of radon-222 from residual radioactive material to the atmosphere would not exceed an average release rate of 20 picocuries per square meter per second (20 pCi/m^2/s). Preliminary calculations conducted by Auxier & Associates using the approach described in Appendix F of the SFS indicate that a cover system employing a GCL layer in lieu of the ROD-selected remedy two-foot thick low permeability layer would result in a similar level of radon attenuation thereby limiting radon emissions to 20 pCi/m^2/s or less.

The landfill cover system constructed over Areas 1 and 2 of the West Lake Landfill must also be able to meet the 200-year longevity effectiveness requirement identified as a potentially relevant and appropriate requirement (EMSI, 2006 and 2011 and EPA, 2008) of the UMTRCA regulations. Similar to the low permeability layer of the ROD-selected remedy cover, the bentonite material component of the GCL would be relied upon to meet this 200 year longevity requirement. In contrast to geomembrane materials such as HDPE, the bentonite component of the GCL is a natural earth material that has been processed for inclusion into the GCL. Subject to proper design and installation factors, the service life of a GCL used in a composite liner system should be on the order of thousands of years (NAS-NRC, 2007 and Rowe, 2005).

For purpose of this evaluation of potential effectiveness, no consideration will be given to any potential benefits that may accrue from inclusion of a synthetic geomembrane in the GCL component of the cover system. Evaluation of possible inclusion of a geomembrane with the GCL may be conducted as part of evaluation of an alternative landfill cover design during the

Supplemental SFS. Simulated landfill liner aging studies conducted by Rowe and Islam (2009) estimate the service life for a composite liner comprised of 60 mil HDPE to vary in the range from 20 to 3,500 years depending on the exposure conditions. Based on the Row and Islam aging studies, for the long-term exposure and temperature conditions expected for a landfill cover system constructed over Areas 1 and 2 of the West Lake Landfill (i.e., not exposed to leachate and a cover temperature less than 37^{o}C), the geomembrane component alone is estimated to have a service life of at least 1,900 years. Koerner et al. (2011) predicted geomembrane lifetimes under unexposed and exposed conditions considering various degradation mechanisms. Their lifetime prediction for HDPE in an unexposed condition and an in-service temperature of 20^{o}C is 446 years. Therefore, if the GCL were to contain a 60-mil thick HDPE geomembrane component, the synthetic geomembrane by itself would also meet the UMTRCA longevity requirement providing redundancy to the bentonite component of the GCL.

GCLs are uniformly manufactured in a controlled environment with consistent-quality materials under numerous American Society for Testing Materials (ASTM) specifications (e.g., ASTM D6768 for tensile strength, D5993 for mass per unit area of composite GCL, D6766 for GCL permeability, and D5261 for geotextile mass per unit area), which allows for certainty during design and eliminates the need to perform the same level of quality control testing on GCLs as CCLs during installation. Manufacturer's quality control test reports for the rolls of GCL can be requested prior to materials delivery to the construction site and samples can be sent for independent quality assurance conformance testing. In contrast, compacted low permeability layers constructed from natural clay materials require rigid construction quality control testing to verify layer thickness, moisture content, density, and compaction in order to verify that the required permeability has been achieved.

4.2 Implementability

Use of a GCL as an alternative to a CCL offers significant advantages (Carson, 2001) including:

- Consistent hydraulic properties,
- Consistent engineering properties,
- Relatively high manufacturer quality control,
- Ease of availability,
- Simplified installation and construction quality control,
- Some self-healing capabilities,
- Simplified repair,
- Simplified installation of penetrations through the cover, and
- Cost competitiveness with CCL.

Each of these advantages is discussed further below.

Currently manufactured GCLs have a hydraulic conductivity of 5 x 10^{-9} cm/sec or less which makes them very effective hydraulic barriers (CETCO, 2013). Because GCLs include pure processed bentonite and are a manufactured product that is subjected to extensive quality control at the manufacturing facility, GCLs are expected to possess more consistent hydraulic and engineering properties and require significantly less construction quality control compared to a CCL.

The alternate GCL landfill cover described above includes a one-foot thick foundation layer for the GCL. As part of the Supplemental SFS for OU-1, a 6-inch foundation layer that would reduce the thickness of the overall cover system could be evaluated for effectiveness and implementability. A reduction in the thickness of the overall landfill cover system could reduce the amount of waste regrading (cut/fill) needed to install a new landfill cover over the OU-1 areas.

There are several manufacturers of GCLs and GCL materials can be shipped anywhere. Since an onsite source of low permeability soil is not available at the West Lake Landfill site, low permeability soil of consistent quality would need to be imported to construct the landfill cover included in the ROD-selected remedy. Because a GCL can provide the same or potentially better performance with a smaller volume of material, less material would need to be shipped to the site to construct a GCL as compared to importation of soil needed to construct the low permeability soil layer included in the ROD-selected remedy; however, the need to provide a suitable foundation and cover material for the GCL likely would offset such an advantage.

Installation of a GCL is relatively simple, requiring nothing more than preparation of a suitable foundation layer, placing and unrolling the GCL material with light construction equipment, overlapping of adjacent layers of GCL possibly with placement of a bentonite strip or dry bentonite powder between the overlapping sheets, followed by placement of the one-foot thick ballast layer over the GCL. Moisture conditioning and compaction of a CCL typically requires a significant volume of water and is difficult during periods of prolonged sub-freezing temperatures. Installation of a GCL is anticipated to be easier and require less time to install as compared to a CCL. Richardson et al. (2002) indicate that far fewer things can go wrong with the installation of a GCL compared to placement and compaction of a compacted clay liner. GCLs are not only much easier to monitor during construction, but also provide a higher level of visible and quantifiable quality assurance in verifying the installed manufactured product meets the design intent.

Installed GCLs exhibit little, if any, change in permeability when subjected to multiple freeze-thaw cycles or alternate wet and dry cycles (Bouazza and Bowders, 2010). In contrast, the hydraulic properties of a CCL can deteriorate significantly if subjected to freeze-thaw cycles. Nevertheless, since the landfill cover at the West Lake Landfill site would include a one-foot vegetation layer, either a GCL or CCL would be protected from freeze/thaw cycles.

The swell characteristics of bentonite allow a GCL to naturally seal punctures. Any damage that may occur to the GCL during construction and is identified can be easily repaired through replacement of the damaged portion with a larger overlapping section of GCL. Any intrusions that may need to be made into the landfill cover in the future, for example penetrations associated with installation of landfill gas extraction wells, would be easily repaired through placement of bentonite powder, granules or pellets into and around small openings and/or placement of additional sheets of GCL over larger openings.

There are some potential disadvantages to use of a GCL (EPA, 2004 and Geosynthetic Institute, 2013); however these disadvantages can be managed and accounted for in the cover design. The potential disadvantages include:

- Need for a stable subgrade free of large rocks, ruts, or objects that could penetrate through the GCL and/or cause thinning of the GCL;
- Premature wetting and swelling of the bentonite material (unconfined hydration) prior to placement of overlying cover soil;
- Potential for damage to the GCL from vehicle/equipment loading during placement of overlying landfill cover materials;
- Potential for slope failure within the bentonite layer or between the geotextile layer and adjacent soil material that can limit application of GCL on steeper slopes;
- Potential for vegetation roots to penetrate and damage the GCL;
- Replacement of sodium within the bentonite with calcium over time and resultant increase in the permeability of the GCL;
- Potential for GCL panel separation;
- Potential for internal bentonite erosion in the GCL; and
- Potential for total and differential settlement.

The first of these disadvantages would be addressed through placement and proof-rolling of suitable foundation soils prior to placement of the GCL. The second factor would be addressed by placement of cover soil over the GCL immediately after installation of the GCL (within 24 hours). Moreover, the GCL is kept wrapped until placement. This factor could also limit installation of GCL material during periods of sustained precipitation.

Vehicle traffic over a GCL can cause localized extrusion of the bentonite material resulting in thinning of the bentonite layer (EPA, 2004, Carson, 2001). This factor would be addressed through specification of the amount of soil cover to be placed over the GCL and the allowable types of equipment to be used to place the soil cover over the GCL.

Several authors (Bonaparte et al., 2002, Carson, 2001, and Daniel and Scranton, 1996) have identified the potential for slope failures in conjunction with use of GCLs or other geosynthetic products. Technical reports (Bonaparte et al., 2002), EPA evaluations (Carson, 2001) and manufacturer's information (CETCO, 2014) all indicate that GCLs can be used and are expected to remain stable on slopes of 3:1 or 33%. Because the maximum slope angles for final covers are restricted to 25% (4:1) under the Missouri solid waste regulations, inclusion of a GCL in the final cover system would not be expected to pose significant slope stability issues. Some manufactures provide GCLs with greater internal strength and higher roughness factors on the outer geotextile surfaces to increase overall slope stability of a GCL. Regardless, inclusion of a GCL into the landfill cover would require an analysis of slope stability during the design phase.

Both GCL and CCL cover systems are subject to increases in permeability if plant roots are allowed to extend down into or through the low permeability material. This issue would be addressed during design through inclusion of materials/layers that limit root penetration and through operations and maintenance activities including mowing to prevent establishment of woody plants.

GCLs should not be used in areas with high concentrations of leachable calcium, magnesium, or other polyvalent ions (Carson, 2001). Exposure of the GCL to calcium and other polyvalent ions can result in exchange of the sodium within the bentonite by calcium which can increase the permeability of the GCL and reduce the swelling capacity of the bentonite, altering the self-healing capacity of the GCL. In most cases, as long as the GCL is well hydrated (more than 50%) before contact with potentially harmful cations, the GCL hydraulic conductivity will remain low (Benson and Meer, 2009). Local borrow soil materials likely are derived from weathering of the limestone, dolomite, or calcareous shale deposits in the area of the site. Consequently, it is possible that locally available soil materials that could be used for the GCL subgrade and cover materials could potentially contain high concentrations of calcium, magnesium and polyvalent ions. Therefore, if the cover were to include a GCL, the calcium content of the overlying cover components should be specified to prevent the use of high calcium (and especially "leachable" calcium) to minimize the potential for an adverse reaction.

GCL panel separation (installed overlapped seams are compromised, resulting in gaps between GCL panels) can be a concern when a GCL is installed beneath an exposed geomembrane for an extended period of time (i.e., several months or years). This effect can be controlled by increasing GCL overlaps, using a GCL with a woven component, placing confining cover soil in a timely manner, and/or heat tacking the GCL panels.

High hydraulic gradients in combination with the placement of a GCL over coarse grained soils, fine grained soils or open structures (geonets) can cause internal bentonite erosion ("piping"). Internal bentonite erosion can be controlled by using a plastic-laminated GCL, such as the CETCO Bentomat® CL or CLT (Geosynthetic Institute, 2013).

Because the waste has been present for greater than 40 years, additional total settlement is not anticipated for Areas 1 and 2 at the West Lake Landfill. Any additional total settlement can probably be accommodated if a GCL were in the cover cross section as the GCL would necessarily settle likewise. However, depending on the amounts and locations of fill and contouring of the final cover system for Areas 1 and 2, differential settlement may be of concern.

Differential settlement may be characterized by distortion (i.e., settlement over a horizontal distance). A tensile strain caused by distortion can be computed. If tensile strains are large enough, a low permeability layer in a landfill cover may crack resulting in an increase in its hydraulic conductivity. Published data on tensile strains at failure for CCLs indicate that the tensile strain at failure of compacted clay is typically between 0.1 and 4% (LaGatta et al., 1997). The ability of compacted clays to survive differential settlement in landfill covers has been questioned by Koerner and Daniel (1992) and Daniel and Koerner (1993), based on concerns over the brittleness of compacted clay in tension. The levels of distortion caused by differential settlement often observed in landfill covers are greater than those that would theoretically predict occurrences of cracking in a compacted clay layer. Conversely, tests were performed by LaGatta et al. (1997) to measure the hydraulic conductivity of GCLs that were subjected to differential settlement. In most cases the GCLs maintained a hydraulic conductivity of 1×10^{-7} cm/sec or less when subjected to tensile strains of l to 10%, depending on the material and test conditions. Overlapped GCL panels maintained their hydraulic integrity despite in-plane slippage of up to 25-100 mm. In general, the researchers found that the ability of GCLs to withstand differential settlement appears to be greater than that of CCLs, but less than that of geomembranes (LaGatta et al., 1997). Therefore, under conditions of differential settlement, the effectiveness of a cover employing a GCL is expected to be greater than the effectiveness of a cover where the low permeability layer is comprised of compacted clay.

Other than the possibility that local borrow soil materials could contain high concentrations of calcium, magnesium and polyvalent ions, no significant factors that would prevent or limit use of a GCL in the landfill cover design were identified. Overall, the potential advantages of possible inclusion of a GCL in the landfill cover design are significant and the possible disadvantages are minimal and can generally be addressed through proper design, installation and quality control. Therefore, inclusion of a GCL in the landfill cover design is considered implementable.

4.3 Cost

Preliminary capital cost estimates for a cover employing a GCL system described in Section 4.1 as a substitute for the two-foot thick CCL included in the ROD-selected remedy profile indicate that costs are similar to those estimated in the SFS for the ROD-selected remedy that includes the two-foot thick CCL. Carson (2001) indicates that the costs for construction of a GCL cover system were similar to, or potentially less than the costs associated with an equivalent CCL. Smith and Athanassopoulos (2013) found that, when both capital and long-term management costs are considered, it would be economically beneficial to construct a geosynthetic composite cover in lieu of a compacted clay cover or an ET cover for mining waste sites. Therefore, use of a cover employing a GCL system as a replacement for the low permeability component of the engineered landfill cover included in the ROD-selected remedy is expected to be cost effective for West Lake OU-1.

5. SUMMARY AND RECOMMENDATIONS

The results of the evaluation of the potential effectiveness, implementability and cost indicate that use of a GCL system as a substitute for the two-foot thick CCL included in the ROD-selected remedy profile is implementable and can provide greater effectiveness at minimizing infiltration at comparable cost. Therefore, use of an alternative cover design that includes a GCL component is recommended for development and evaluation in the Supplemental SFS.

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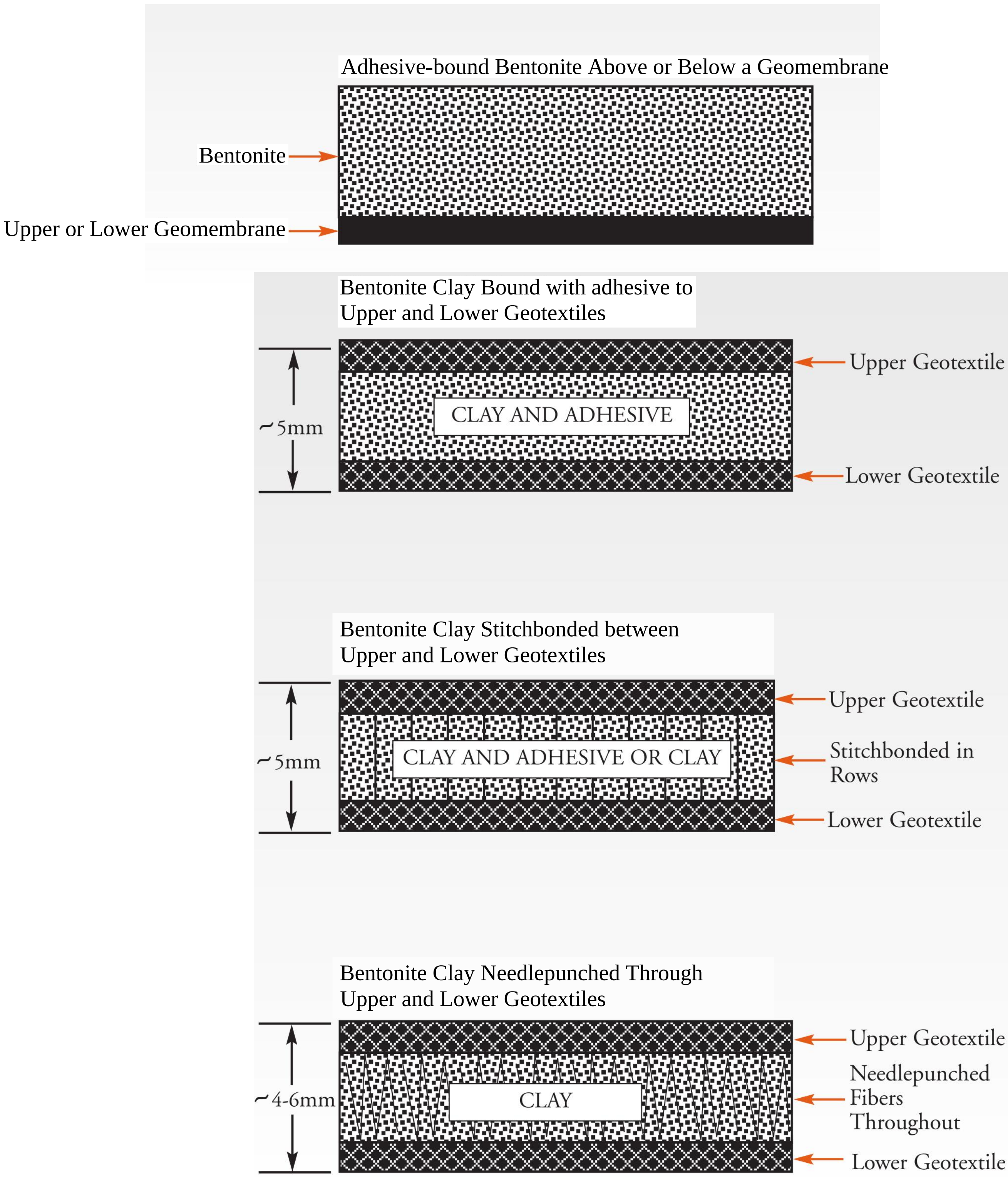

Figure 1

Cross Sections of
Typical GCLs

West Lake Landfill OU-1

EMSI Engineering Management Support, Inc.

Note: Thicknesses shown are non-hydrated
Sources: EPA, 2001 and Bouazza and Bowders, 2010